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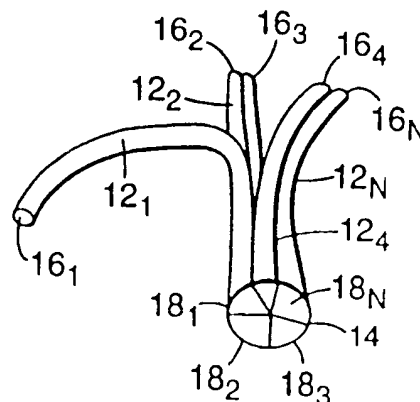
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(54) Title: ILLUMINATION DEVICE AND METHOD FOR MAKING THE SAME

(57) Abstract

A light transport device comprises light (12, 12₂, ... 12_n) that individually have predetermined cross sections at one end (18, 18₂, ... 18_n) that may be bundled together essentially without deformation to provide a continuous plane, suitable for light input or output, that is substantially free of voids and free of non-light-transmitting materials. The other end (16, 16₂, ... 16_n) of the individual light fibers has a cross section that is useful for injection or emission of light from a single fiber.



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ILLUMINATION DEVICE AND METHOD FOR MAKING THE SAME

FIELD OF THE INVENTION

5 The present invention relates generally to methods and apparatus for manufacturing an illumination device, and more particularly, to a method and apparatus for manufacturing an illumination device in which light extraction structures are molded in an overlay that is directly adhered to a light guide during the manufacturing process.

10

BACKGROUND OF THE INVENTION

 Optically transmissive materials, such as glass or polymers, may be used as a light guide to propagate light. A light guide typically includes at least one surface adapted to receive light from a light source and an optically smooth surface for reflecting light propagating through the light guide. Common examples of light
15 guides include the optical fibers traditionally used in the data communication industry, and the planar waveguides used in the optical display industry

 Light fibers are also used as components in illumination systems, as disclosed in, for example, U.S. Patent No. 5,225,166 (Zarian et al.). In these
20 systems, light is injected into at least one end of a light fiber and allowed to exit the fiber at a predetermined position or positions along the length of the fiber

 Methods for encouraging light to exit an optical fiber at a desired location are known as extraction techniques. Many extraction techniques cause light to leak from a light fiber in an uncontrolled fashion. Such techniques include subjecting the
25 fiber to relatively sharp bends (generally known as "microbends") and removing and/or roughening a portion of the optical fiber core or cladding to provide a diffuse surface which causes light to escape.

 Extraction techniques are also known which cause light to be extracted from an optical fiber in a controlled fashion. One such technique is disclosed in U.S.

The technique described in Davenport et al. has a number of limitations, however. For example, the light fibers must be formed from a compression-deformable material. Hence, the technique precludes the use of non-deformable materials such as glass. In addition, a sleeve having a tapered bore is required for receiving and compressing the
5 fibers. Also, the device requires cladding material, which surrounds the fiber core within the bundled input end. The cladding material consumes space within the bundle, so that proportionately less light can be introduced into the fibers (or, proportionately fewer fibers can be included within the bundle). Removing the cladding (which is not described in the '985 patent) would constitute an extra costly and time-consuming step. Finally,
10 compressing the fibers in the manner required by this patent may create non-uniformities through cross-sections of the fibers, which may introduce scattering points in the fibers.

There is thus a need in the art for a light transfer device comprising a plurality of fibers, each having first and second ends, wherein at least the first ends of the fibers are arranged into an injection surface that is substantially free of voids or cladding materials
15 There is also a need in the art for a method for making such a device which does not require compression deformation of the fibers in the vicinity of the injection surface or the use of a compression sleeve. These and other needs are met by the present invention, as hereinafter described.

20 SUMMARY OF THE INVENTION

In one aspect, the present invention relates to a light fiber which is prefabricated with a cross-sectional shape on at least a first end (hereinafter termed the "contacting end"), the cross-sectional shape being such that a plurality of the fibers can be assembled with their contacting ends adjacent to each other so as to form a planar light injection
25 surface which is substantially free of voids, cladding, and other non-light-guiding materials or features. The contacting ends have a prescribed cross-sectional shape prior to contacting one another such that, when they are brought into contact, the outer edges can assume an orientation completely contiguous with one another so that the light injection plane is substantially free of voids while each of the contacting ends maintains its respective
30 prescribed cross-sectional shape.

In some embodiments of this aspect of the invention, at least one of the contacting

ends has a noncircular cross-sectional shape. Such noncircular cross-sectional shapes include, for example, sectors or polygons (e.g., squares, rectangles, hexagons, etc.). In other embodiments, each of the plurality of contacting ends has a unique cross-sectional shape. In still other embodiments, at least one of the contacting ends has an irregular cross-sectional shape

In another aspect, the present invention relates to a device which comprises a plurality of light fibers n_1, \dots, n_k wherein k is an integer greater than or equal to 2, wherein each of the fibers has a contacting end, and wherein the contacting ends are capable of being assembled into a coplanar orientation so as to form an essentially continuous input plane. Each of the k light fibers has a contacting end with a cross-sectional shape corresponding to a sector such that fiber n_i has a sector with an arc length of a_i that subtends an angle ϕ_i , wherein $a_1 + \dots + a_k = 2\pi$ radians, and wherein $\phi_1 + \dots + \phi_k = 360^\circ$. The radii of all k sectors are typically equal, i.e., the fibers can be arranged so that the sectors lie in the same plane and form a circle, although analogous embodiments are also possible wherein the sectors can be arranged to form an ellipse or other geometric shape. The arc lengths of all k sectors are also typically equal, i.e., $a_1 = \dots = a_k$, although in some embodiments, at least two elements a_m, a_n of the set a_1, \dots, a_k are not equal, i.e., $a_m \neq a_n$.

In another aspect, the present invention relates to a device comprising a plurality of fibers, each of the fibers having a contacting end, wherein the contacting ends are capable of being assembled into a coplanar orientation so as to form an essentially continuous input plane. Each of the contacting ends has a prescribed cross-sectional shape prior to contacting one another that is conformably coated by a cladding layer, the cladding layer comprising a material/substance having a refractive index less than that of the light fiber that comprises the contacting end. Preferably, the cladding layer is thin and constitutes a small percentage of the total surface of the continuous plane.

In the various embodiments of the various aspects of the present invention, the non-contacting end of at least one of the light fibers may have a circular cross-section. Alternatively, in some embodiments of the invention, the non-contacting end of at least one of the light fibers has a cross-sectional shape corresponding to the prescribed cross-sectional shape of its contacting end. In other embodiments, the non-contacting end of at least one of the light fibers has a cross-sectional shape different from the prescribed cross-

sectional shape of the contacting end. In those embodiments where the contacting and non-contacting ends of a light fiber differ in shape, the light fiber may undergo a transition from the cross-sectional shape of its contacting end to the cross-sectional shape of its non-contacting end. This transition may occur over a predetermined portion of the length of the light fiber, which in some cases may be the entire length of the fiber.

In a further aspect, the present invention relates to a device comprising a plurality of light fibers, each having a contacting end. The contacting ends are arranged into a light injecting plane that is substantially free of both voids and non-light guiding material such as a cladding, i.e., the adjacent fiber cores are in direct contact with one another.

In yet another aspect, the present invention relates to a method for transporting light from a single source to multiple prescribed locations. In accordance with the method, light is directed into a light injection plane formed by a plurality of light fiber input ends. The input ends of each light fiber have a prescribed cross-sectional shape selected such that adjacent input ends have outer peripheries contiguous with one another so that the light injection plane is substantially free of voids or other non-light-guiding materials. The output ends of the light fibers are then oriented so that light emitted therefrom is applied to the respective prescribed locations.

In still another aspect, the present invention relates to a method for making a light transport device. In accordance with the method, a plurality of light fibers are provided, each having a contacting end and a non-contacting end. The contacting end of each of the light fibers has a prescribed cross-sectional shape prior to being brought into contact with one another. The prescribed cross-sectional shapes are selected so that, when the outer edges of the contacting ends are brought together in a given orientation, they contact one another in a completely contiguous manner. The contacting ends are then arranged in a light injection plane such that the outer edges of adjacent contacting ends are completely contiguous with one another so that the light injection plane is substantially free of voids and non-light-guiding material.

BRIEF DESCRIPTION OF THE DRAWINGSDESCRIPTION OF THE DRAWINGS

FIG. 1 depicts a perspective view of an exemplary light transport device constructed in accordance with the present invention;

FIG. 2 depicts a front view of the light injection surface seen in FIG. 1;

5 FIG. 3 depicts an alternative embodiment of the light injection surface shown in FIG. 2, in which different fibers have different radial extents; and

FIG. 4 depicts an alternative embodiment of the light injection surface shown in FIG. 2, in which the fibers have rectangular cross-sectional shapes.

10 DETAILED DESCRIPTION

As used herein, the term "sector" shall be used in reference to a geometric figure bounded by two radii and the included arc of a circle.

FIG. 1 depicts a perspective view of a light transport device constructed in accordance with the present invention. A plurality of light fibers 12₁, 12₂, ... 12_N are
15 brought into contact with one another at their respective input ends 18₁, 18₂, ... 18_N. Input ends 18₁, 18₂, ... 18_N form a light injection surface 14 into which light from a light source is directed. As is well known, light injected into the individual input ends of each fiber is transported along the fiber core in accordance with the principles of total internal reflection. Fibers 12₁, 12₂, ... 12_N have output ends 16₁, 16₂, ... 16_N that emit the light transmitted
20 therethrough. Since the light fibers are flexible and need to remain in contact with one another only at their input ends, the output ends of the light fibers may be arranged in any desired configuration so that light can be provided to different locations. For example, as seen in FIG. 1, fibers 12₁, 12₂, and 12₄ each emit light in a different direction.

As best illustrated in FIG. 2, the input ends 18₁, 18₂, ... 18_N of light fibers 12₁, 12₂,
25 ... 12_N have cross-sectional shapes that differ from the circular shape of a conventional light fiber. Specifically, in the exemplary embodiment of the invention shown in FIGS. 1 and 2, the input ends of the light fibers are sectors which contact one another without creating any empty space or voids therebetween. That is, the outer edge surfaces of the input ends of adjacent fibers are completely contiguous with one another. Since this
30 exemplary embodiment of the present invention employs five light fibers, each input end is a sector that subtends an angle of 72 degrees. Of course, if a fewer or greater number of

fibers are employed, the arc length and associated angle of each sector can be adjusted accordingly to form a light injection surface that is essentially circular. The sectors need not be of equal area. For example, three sectors could each subtend an angle of 60 degrees, while the remaining two sectors could subtend angles of 90 degrees each.

5 While the light transport device of the present invention may be described as a device for transporting light from a single source to a plurality of different locations, one of ordinary skill in the art will recognize that the device can be employed in reverse. That is, the device can transport light from a plurality of sources to a single location by applying light to the output ends shown in FIG. 1 and using plane 14 as a light emission plane. In
10 this regard it should be recognized that the terms "input" and "output" as used herein to define opposing ends of light fiber are employed for descriptive purposes only and should not be construed as limiting their applicability to receiving and emitting light, respectively. In other words, in appropriate circumstances, the "input ends", as described above, may be employed to emit light and "output ends", as described above, may be employed to receive
15 light.

One of ordinary skill in the art will recognize that light injection surfaces may be formed from many different packing configurations in accordance with the principles of the present invention. For example, the sectors shown in FIG. 2 need not have the same dimensions. Rather, as shown in FIG. 3, the sectors may differ in radial extent. In FIG. 3,
20 for example, fiber 32₁ extends over 180 degrees, fiber 32₂ extends over 135 degrees, and fiber 32₃ extends over 45 degrees. Moreover, the cross-sectional shape of the fiber input ends need not be sectors. FIG. 4 shows an alternate configuration, in which the light injection surface comprises a number of rectangular ends. Each end 48₁, 48₂, ... 48_N of fibers 42₁, 42₂, ... 42_N can have a cross-section that is approximately square, and fibers 42₁,
25 42₂, ... 42_N can be molded so as to have an approximately circular cross-sectional configuration at respective output ends 46₁, 46₂, ... 46_N. In general, the input ends of the light fibers can have any shape, regular (e.g., hexagonal or polygonal) or irregular, provided the resulting light injection surface is substantially free of voids. Additionally, the shape of the input ends need not all be the same. For example, the light fibers may be irregular
30 shapes that interlock with one another, analogous to the pieces of a puzzle.

In some embodiments of the invention the light injection surface is free not only of

voids, but also of any materials or features (e.g., cladding) that interfere with the transmission of light into the fibers. In other words, the light fibers may consist simply of a core that is free of any surrounding cladding material. In these embodiments of the invention, adjacent fiber cores are in direct contact with one another.

5 In other embodiments of the invention, some cladding material may be present at the light injection surface. In these embodiments, the cladding material conformably coats each of the shaped light fiber ends. Preferably, the cladding material is thin and constitutes a minor percentage of the light injection surface.

The particular packing arrangement that is used for any given application will be
10 determined by a number of parameters, including the number of light fibers employed, the cross-sectional areas of the individual fibers (fibers with a greater cross-sectional area will transport a greater fraction of the total available light), and the cross-sectional shape of the input ends of the fibers. The values of these parameters will in turn be selected based on the given application for which the light transport device is to be used.

15 As seen in FIG. 1, the light fibers may undergo a gradual transition in their cross-sectional shape between their respective input and output ends. In the FIG. 1 embodiment, for example, while the input ends are shaped as sectors, the output ends are circular in shape, as in a conventional light fiber. The transition may occur over the entire length of fiber, or only over a portion thereof. In general, the cross-sectional shape of the input ends
20 of the light fibers may be selected independently of the cross-sectional shape of the output ends. That is, the input and output ends may or may not have the same cross-sectional shape. While the shapes of the input and output ends of the light fibers may differ, it is advantageous in many embodiments that the fibers maintain substantially the same total cross-sectional area across their lengths so that light loss from the fiber is minimized.

25 The input ends of the light fibers forming the light injection surface may be held in place at the light input area by heat shrink tubing or by other appropriate mechanical or chemical bonding means.

The individual light fibers of the light transport device of the present invention may be fabricated in a molding process using, for example, a conventional two piece mold
30 Alternatively, the mold may be an expandable mold of the type disclosed in U.S. Application Serial No. 09/026,836, entitled "Method and Apparatus for Seamless

Microreplication Using an Expandable Mold." Briefly, an expandable mold is formed from a flexible material having a generally hollow portion that corresponds to the shape of the desired finished article (i.e., the light fiber). The hollow portion is accessible through at least one opening. The hollow portion is filled with a curable material that hardens in the shape of the hollow portion of the mold. Once hardened, the finished article is removed by applying a pressure differential between the inside and outside of the mold so that the walls of the mold distend to facilitate removal of the molded article. Additional details concerning the expandable mold may be found in the previously mentioned patent application, which is hereby incorporated by reference in its entirety (including drawings) as if repeated herein.

Regardless of the type of mold that is employed, the curable material that forms the finished article may be any material that cures into a substantially optically transparent material and which can be introduced into the mold and cured at temperatures and/or pressure conditions that do not adversely affect the mold. The curable material may be curable by heat, radiation, or other known processes. Suitable curable materials are well known to the art and include polymerizable compounds and mixtures. Acrylates are a class of curable materials that are preferable for their transparency properties. Urethanes are also a desirable class of curable materials because their contraction during curing tends to be minimal, although only certain formulations have desirable transparency properties. Silicones comprise another desirable class of curable materials because of their transparency and heat resistance. Advantageously in the present invention, rigid materials, including rigid thermoplastics such as poly(methyl methacrylate, PMMA) or polycarbonate, can also be used in the present invention, since the prescribed cross-sectional shapes of the input ends are designed to intimately contact one another within a harness or bundle without substantial deformation.

The mold itself is fabricated from a molding master that is a positive replica of the finished light fiber. The master must be fabricated with a precision equal to the precision required of the geometry of the finished light guide. Such a high precision master can be fabricated from a machinable stock material capable of being separated from the molding material after the molding material has cured. For example, the stock material may comprise a machinable metal or a hard polymer. Suitable metals include copper and

aluminum, and alloys such as brass. Suitable polymers include acrylics, carbonates, and any other polymer that may be machined and which retains its shape.

The molding master also may be fabricated by any of a number of rapid prototyping techniques known in the art such as, for example stereolithography. Once the shape of the master is determined and electronically stored in a Computer-Aided Design (CAD) file, suitable equipment is used to create a three-dimensional part representing the part design. In the case of stereolithography, the equipment, under the direction of the CAD file, drives a laser beam that selectively writes a trace on the surface of a photocurable polymer. As the laser beam travels according to the part design, it cures the polymer in layers. As the layers build up, a three-dimensional part is formed. This part is then removed and polished to an optical finish to be used in mold making. See, for example, W. Bruce Campbell, *Rapid Prototyping and Silicone Moldmaking Materials*, Dow Corning Corporation (1996) Form No. 10-702-96.

The molding material from which the mold is fabricated is a liquid composition that can be solidified during a curing process. The material is preferably one that undergoes low shrinkage during the curing process and is relatively easily removable from the master. The molding material should also be chosen to reduce adherence with the molded article so that the molded article can be readily released from the mold. Suitable curable materials are well known to the art and include, for example, elastomers such as a silicone elastomers. Alternatively, when a relatively rigid thermoplastic light guide is desired, injection molding methods that are well known to those of ordinary skill in the art can be used advantageously.

The preceding description of the present invention is merely illustrative, and is not intended to be limiting. Therefore, the scope of the present invention should be construed solely by reference to the appended claims.

What is claimed is:

1. An apparatus for transporting light, comprising
a plurality of light guides, each of said light guides having first ends which are
assembled, essentially without deformation, into a surface that is essentially free of voids,
5 the interior of said surface being essentially free of cladding materials
2. The apparatus of claim 1, wherein said surface is substantially planar
3. The apparatus of claim 1, wherein each of said first ends is rigid
10
4. The apparatus of claim 1, wherein said first ends have outer perimeters, the adjacent
edges of which are contiguous with one another
5. The apparatus of claim 1, wherein at least one of said light guides has a first and
15 second end, wherein said first end has an essentially non-circular cross-section, and wherein
said second end has an essentially circular cross-section.
6. The apparatus of claim 1, wherein each of said light guides has a first end and a
second end, and wherein each of said second ends has an essentially circular cross-section
20
7. The apparatus of claim 1, wherein each of said plurality of first ends has a unique
cross-sectional shape.
8. The apparatus of claim 1, wherein said first ends have essentially identical cross-
25 sectional shapes.
9. The apparatus of claim 1, wherein the first and second ends of said light guides have
essentially identical cross-sectional shapes
- 30 10. The apparatus of claim 1, wherein each of said plurality of light guides has a
longitudinal axis, and wherein the cross-sectional shape of each of said plurality of light

guides undergoes a transition along said longitudinal axis from a first cross-sectional shape to a second cross-sectional shape.

5 11. The apparatus of claim 10, wherein said transition occurs over substantially the entire length of the light guide.

12. The apparatus of claim 1, wherein at least one of said first ends has a noncircular cross-sectional shape.

10 13. The apparatus of claim 12, wherein said noncircular cross-sectional shape is essentially a sector.

14. The apparatus of claim 1, wherein said apparatus comprises N light guides, where N is an integer greater than 1, and wherein each of said N light guides has a cross-sectional
15 shape essentially defining a sector.

15. The apparatus of claim 14, wherein each of said N sectors subtends an angle of $360/N$ degrees

20 16. The apparatus of claim 14, wherein a first of said N sectors subtends an angle ϕ_1 , wherein a second of said N circular sections subtends an angle ϕ_2 , and wherein $\phi_1 \neq \phi_2$.

25 17. The apparatus of claim 1, wherein each of said first ends has a cross-section that essentially describes a polygon.

18. The apparatus of claim 17, wherein said polygon is a hexagon

19. The apparatus of claim 18, wherein said polygon is a rectangle

30

20 The apparatus of claim 1, further comprising binding means for releasibly binding

said light guides together.

21. The apparatus of claim 20, wherein said binding means comprises a band disposed about the exterior surfaces of said light guides in the vicinity of said first ends.

5

22. An apparatus for transporting light, comprising:
 an arrangement of N light guides, where N is an integer greater than 1, each of said N light guides terminating in a substantially planar terminal surface such that, for $k=1$ to N, the k^{th} terminal surface essentially defines a sector S_k which subtends an angle ϕ_k ,
 wherein the sum

10

$$\sum_{k=1}^N \phi_k$$

15

is essentially 2π radians, and wherein the terminal surfaces of said light guides are arranged into an essentially planar surface which is substantially free of voids.

23. The apparatus of claim 22, wherein said planar surface has an essentially circular perimeter.

20

24. The apparatus of claim 22, wherein the terminal surfaces are arranged into the planar surface without substantial deformation.

25. The apparatus of claim 22, wherein said terminal surfaces are rigid.

25

26. An apparatus for transporting light, comprising:
 an arrangement of N light guides, where N is an integer greater than 1, each of said N light guides terminating in a substantially planar terminal surface such that, for $k=1$ to N, the k^{th} terminal surface essentially defines a rectangle R_k , and wherein the terminal surfaces of said light guides are essentially arranged into a rectangle R which is substantially free of voids

30

27. The apparatus of claim 26, wherein each of said terminal surfaces are rigid

28. The apparatus of claim 26, wherein the rectangles in the set R_1, \dots, R_N have essentially the same dimensions
- 5 29. The apparatus of claim 26, wherein, for $k = 1$ to N , the k^{th} light guide has a cross-sectional shape which undergoes a transition along the longitudinal axis of said light guide from a first cross-sectional shape describing the rectangle R_k to a second cross-sectional shape.
- 10 30. The apparatus of claim 28, wherein said second cross-sectional shape is circular.
31. A method for making an optical device, comprising the steps of:
providing a plurality of light guides, each of said light guides terminating in a first end, and
15 assembling the first ends, essentially without deformation, into a surface that is essentially free of voids, the interior of said surface being essentially free of cladding materials.
32. The method of claim 31, wherein said surface is substantially planar.
- 20 33. The method of claim 31, wherein each of said first ends are rigid.
34. The method of claim 31, wherein said first ends have outer perimeters, the adjacent edges of which are contiguous with one another.
- 25 35. The method of claim 31, wherein at least one of said light guides has a first and second end, wherein said first end has an essentially non-circular cross-section, and wherein said second end has an essentially circular cross-section
- 30 36. The method of claim 31, wherein each of said light guides has a first end and a second end, and wherein each of said second ends has an essentially circular cross-section

37. The method of claim 31, wherein each of said plurality of first ends has a unique cross-sectional shape.

5 38. The method of claim 31, wherein said first ends have essentially identical cross-sectional shapes.

39. The method of claim 31, wherein the first and second ends of said light guides have essentially identical cross-sectional shapes

10

40. The method of claim 31, wherein each of said plurality of light guides has a longitudinal axis, and wherein the cross-sectional shape of each of said plurality of light guides undergoes a transition along said longitudinal axis from a first cross-sectional shape to a second cross-sectional shape.

15

41. The method of claim 40, wherein said transition occurs over substantially the entire length of the light guide.

20 42. The method of claim 31, wherein at least one of said first ends has a noncircular cross-sectional shape.

43. The method of claim 32, wherein said noncircular cross-sectional shape is essentially a sector.

25 44. The method of claim 31, wherein said apparatus comprises N light guides, where N is an integer greater than 1, and wherein each of said N light guides has a cross-sectional shape essentially defining a sector.

30 45. The method of claim 44, wherein each of said N sectors subtends an angle of $360/N$ degrees

46 The method of claim 44, wherein a first of said N sectors subtends an angle ϕ_1 , wherein a second of said N circular sections subtends an angle ϕ_2 , and wherein $\phi_1 \neq \phi_2$.

5 47. The method of claim 31, wherein each of said first ends has a cross-section that essentially describes a polygon.

48. The method of claim 47, wherein said polygon is a hexagon.

10 49. The method of claim 48, wherein said polygon is a rectangle.

50. The method of claim 31, further comprising binding means for releasibly binding said light guides together.

15 52. The method of claim 50, wherein said binding means comprises a band disposed about the exterior surfaces of said light guides in the vicinity of said first ends.

53. A method for making an optical device, comprising the steps of:
providing a plurality of light guides G_1, \dots, G_N , wherein, for $k=1$ to N , the k^{th} light
20 guide terminates in a planar first end which essentially defines a sector S_k which subtends an angle ϕ_k , and wherein $\phi_1 + \dots + \phi_N = 2\pi$ radians; and
assembling said first ends into a substantially coplanar arrangement, thereby forming a light input surface.

25 54. The method of claim 53, wherein the interior of said light input surface is substantially free of voids

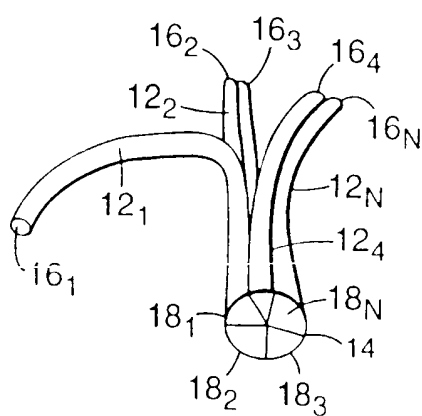
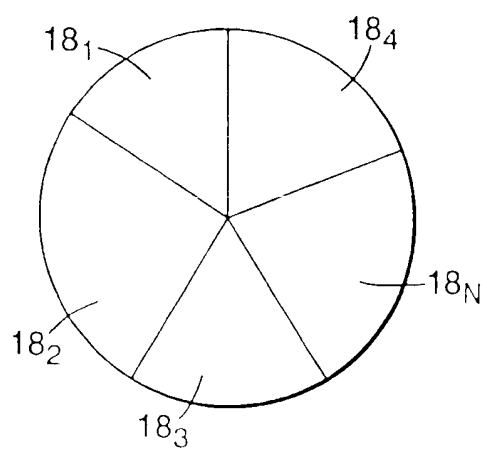
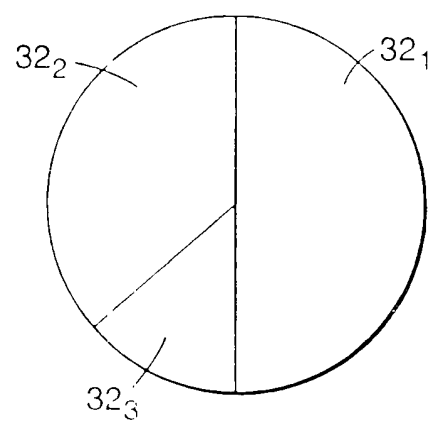
55. The method of claim 53, wherein said first ends are rigid.

30 56. The method of claim 53, wherein each of the first ends has a prescribed cross-sectional shape, prior to being assembled into the coplanar arrangement, such that, when

the first ends are arranged into the coplanar arrangement, the adjacent edges of the first ends are contiguous with one another.

57. The method of claim 53, wherein a first sector S_1 of the N sectors and a second
5 sector S_2 of the end sectors are such that $\phi_1 \neq \phi_2$.

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**Fig. 1****Fig. 2****Fig. 3**

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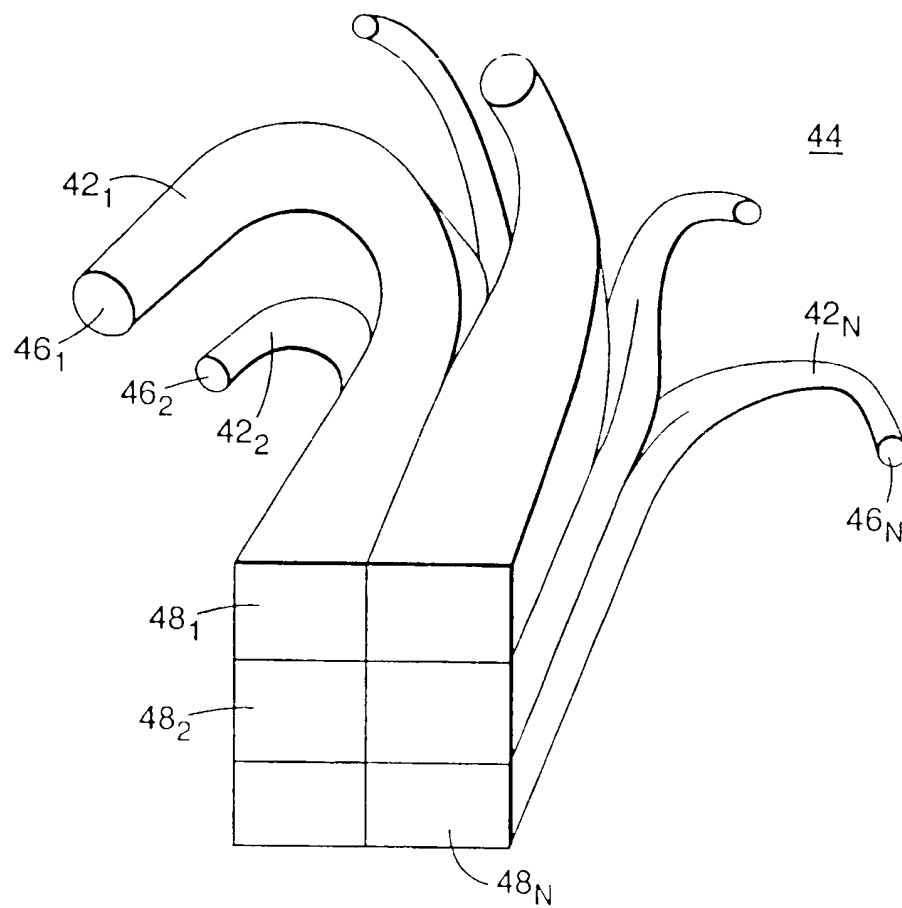


Fig. 4

INTERNATIONAL SEARCH REPORT

International Application No.

PCT/US 99/08641

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 G02B6/06 F21V8/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 6 G02B F21V

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4 743 082 A (MORI KEI) 10 May 1988	1-12, 17, 18, 20, 21, 31-42, 47, 48, 50, 52
Y	see column 2, line 27 - column 3, line 7; figures 1-5	13-16, 22-25, 43-46, 53-57

	-/-	

☒ Further documents are listed in the continuation of this C

☒ Patent family members are listed in annex

1. Special categories of cited documents

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- (D) document referring to an oral disclosure, use, exhibition or other means
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Date of the actual completion of the international search

Date of making of the international search report

15 July 1999

30/08/1999

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INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 99/08641

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication where appropriate of the relevant passages	Relevant to claim No
X	US 5 346 655 A (BLYLER JR LEE L ET AL) 13 September 1994	1-12, 17, 19-21, 26-42, 47, 49, 50, 52
Y	see column 3, line 22 - line 42; figure 5	13-16, 22-25, 43-46, 53-57
Y	US 5 058 985 A (DAVENPORT JOHN M ET AL) 22 October 1991	13-16, 22-25, 43-46, 53-57
A	EP 0 284 098 A (FUJI PHOTO FILM CO LTD) 28 September 1988 see column 5, line 36 - column 6, line 5; figure 2	9, 39

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/US 99/08641

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
US 4743082	A	10-05-1988	NONE	
US 5346655	A	13-09-1994	US 5153932 A	06-10-1992
US 5058985	A	22-10-1991	CA 2042144 A	24-01-1992
			DE 69113708 D	16-11-1995
			DE 69113708 T	30-05-1996
			EP 0468723 A	29-01-1992
			JP 2084740 C	23-08-1996
			JP 4234011 A	21-08-1992
			JP 7113692 B	06-12-1995
EP 0284098	A	28-09-1988	JP 2566403 B	25-12-1996
			JP 63236025 A	30-09-1988
			JP 63314504 A	22-12-1988
			DE 3884986 D	25-11-1993
			DE 3884986 T	17-02-1994
			US 4824194 A	25-04-1989